

## SEMICONDUCTOR DIODE WITH REDUCED RECOVERY CURRENT

### BACKGROUND OF THE INVENTION

#### 1. Field of the Invention

The present invention relates to a diode.

#### 2. Description of the Background Art

FIG. 1 is a cross sectional view showing a structure of a conventional diode 200. In FIG. 1, an N<sup>-</sup> body 2 and an anode P layer 31 are stacked in this order on a cathode N<sup>+</sup> layer 1. A cathode electrode 7 is disposed under the cathode N<sup>+</sup> layer 1 and an anode electrode 6 is disposed on the anode P layer 31.

FIG. 2 shows a characteristic of a current which flows in the diode 200 in response to a voltage applied between the anode electrode 6 and the cathode electrode 7. When a higher potential is given to the anode electrode 6 than to the cathode electrode 7, the diode 200 is forward-biased. At a certain threshold voltage  $V_{TH}$  (about 0.6 V), current suddenly starts flowing.

This is because the resistance of the N<sup>-</sup> body 2 substantially drops due to shift of holes from the anode P layer 31 to N<sup>-</sup> body 2 at the threshold voltage  $V_{TH}$  or a voltage higher than that, and hence, the current capacity of the diode 200 increases.

On the other hand, a lower potential applied to the anode electrode 6 than to the cathode electrode 7 renders the diode 200 biased in the reverse direction. Hence, current will not be initiated until a certain low potential is reached. With a potential below that certain low potential, current starts flowing. A voltage applied to the diode 200 at the initiation of current is a breakdown voltage. In FIG. 2, the breakdown voltage is indicated at  $V_{BR}$ .

To increase the breakdown voltage  $V_{BR}$ , the electric field, developed at an end portion of the anode P layer 31, has to be weakened. An approach taken to weaken the electric field is to provide a breakdown voltage in the diode holding structure such as a guard ring, although no such structure is shown in FIG. 1. If such structure is to be provided, the device structure is designed such that the breakdown voltage yielded by the anode P layer 31, N<sup>-</sup> body 2 and the cathode N<sup>+</sup> layer 1 determines the breakdown voltage  $V_{BR}$  while considering the one-dimensional structure of the anode P layer 31, N<sup>-</sup> body 2 and the cathode N<sup>+</sup> layer 1 along their thicknesses.

FIG. 3 shows a characteristic of a current which flows when the diode 200 is forward-biased first and subsequently reverse-biased with a voltage which is lower than the breakdown voltage  $V_{BR}$ . In the graph, a current  $I$  is measured along the vertical axis in such a manner that the current  $I$  during the forward-bias state is shown with positive values. The horizontal axis of the graph denotes time  $T$ . Zero on the horizontal axis corresponds to a time when the forward-bias state is changed to the reverse bias state.

Current keeps flowing in the diode 200 even after the biasing condition changes from the forward bias state to the reverse bias state. During the forward-bias state, holes had migrated to the N<sup>-</sup> body 2 from the anode P layer 31. With a reverse bias applied to the diode 200, excessive holes in the N<sup>-</sup> body 2 are attracted to the anode electrode 6 and excessive electrons are attracted to the cathode electrode 7.

Hence, the current  $I$  decreases for a short period of time after the change from the forward-bias state to the

reverse-bias state. Current of the reverse bias direction then starts to flow ( $I < 0$ ), and at last gradually terminates with end of migration of all carriers such as the excessive holes from the N<sup>-</sup> body 2. The maximum value of the reverse direction current at this stage is called "recovery current  $I_{RR}$ ." The current characteristic which is observed after change from the forward-bias state to the reverse-bias state, as that shown in FIG. 3, is called "recovery characteristic."

A diode, much needed in general, is a high speed soft recovery diode which is characterized by its small and gradual termination of the recovery current  $I_{RR}$ . Without such a diode, an element connected in parallel to the diode is subjected to a surge voltage of the reverse direction, consequently destroying the element.

When the diode 200 constructed as shown in FIG. 1 is forward-biased, holes tend to excessively flow from the anode P layer 31 to the N<sup>-</sup> body 2, and therefore, the recovery current  $I_{RR}$  grows accordingly. Hence, improvement in the recovery characteristic of the diode of such structure should require implantation of a hole lifetime killer in the anode P layer 31, the N<sup>-</sup> body 2 and the cathode N<sup>+</sup> layer 1 to decrease the lifetime of the holes.

However, implantation of a hole lifetime killer not only adds to process complexity, but also increases the ON-resistance (a resistance of the forward-biased diode). Above all, injection of the excessive holes from the anode P layer 31 is left uncorrected.

Under such circumstances, a high speed soft recovery diode structure has been proposed which does not invite migration of excessive holes without introducing a hole lifetime killer. FIG. 4 is a cross sectional view of a diode 300 which is disclosed in literature such as "Proceeding of the 3rd ISPSD" (pgs 109 and 113) and Japanese Laid-Open Gazette No. 52-24465.

Unlike the structure shown in FIG. 1, anode P layers 3 are selectively formed in a top portion of an N<sup>-</sup> body 2. In the top portion of the N<sup>-</sup> body 2 where there are no P layers 3, a shallow P<sup>-</sup> layer 4 is provided. In some cases, the P<sup>-</sup> layer 4 is not disposed and an anode electrode 6 and the N<sup>-</sup> body 2 form a Schottky barrier diode.

In comparison with the diode 200, less holes flow from the anode P layers 3 during the forward-bias state of the diode 300 since the anode P layers 3 are selectively disposed. In other words, the size of the anode P layers 3 are formed in the top portion of the N<sup>-</sup> body 2 controls the amount of injection of the holes into the N<sup>-</sup> body 2.

However, compared with the diode 200, the diode 300 easily causes the concentration of an electric field around a shoulder portion 3a of the anode P layers 3 and also around the P<sup>-</sup> layer 4, which in turn decreases the breakdown voltage  $V_{BR}$ . To avoid this, a wide aperture cannot be formed between the anode P layers 3. That is, the aperture of the anode P layers 3 must be formed in a certain limited width which would not invite a large decrease in the breakdown voltage  $V_{BR}$ .

### SUMMARY OF THE INVENTION

A semiconductor device of a first aspect of the invention comprises: a first conductivity type first semiconductor layer; second conductivity type second semiconductor layers of a relatively high concentration, the second semiconductor layers being selectively formed in a top major surface of the first semiconductor layer;